γ-Ray bursts

- History
  - Discovery
  - Total mystery
  - CGRO-Batse
- Characteristics
  - Spatial distribution
  - Timing properties and distribution
  - Spectral properties
- What are they?
  - All the hypothesis?
  - Prevalent views

History of γ-ray bursts

- Discovery
  - Discovered at the end of the 60's
  - Part of a nuclear monitoring project with the Vela military satellites
- Total mystery
  - Distance unknown
  - No counterpart identified
  - Mechanisms unknown

Between the first discoveries and the next big observatory (CGRO), there were several missions: Russian/French collaboration on PHEBUS (66 burst detected), a γ burst locating instrument on two missions (GRANAT and EURECA), and one operating on the *Ulysses* spacecraft.
Still no answer to even the basic question: where are the bursts coming from?

Before BATSE, what was the consensus?

- Relatively nearby
- Neutron stars mergers?
- Similar phenomena than the ones existing in the Sun

CGRO-(April, 5 1991 to June, 4 2000)

Burst And Transient Source Experiment (BATSE)
Information on the experiment is available at:
http://gammaray.msfc.nasa.gov/batse/ and
http://cossc.gsfc.nasa.gov/cossc/batse/index.html

BATSE was an all sky monitor sensitive from about 20 to 600 keV. BATSE had eight identically configured detector modules. Each detector module contains a Large Area Detector (LAD) optimized for sensitivity and directional response, and a Spectroscopy Detector (SD) optimized for energy coverage and energy resolution.

BATSE detects γ-ray bursts on-board by examining the count rates of each of the eight LADs for statistically significant increases above background on each of three time scales: 64 ms, 256 ms, and 1024 ms. The background rate is determined for each detector over 17.4 seconds. The statistical significance required for a burst trigger is set at 5.5 sigma. At least two detectors must exceed threshold for a burst trigger to occur. An additional requirement for burst triggering is that the detector with the greatest increase in count rate must have an increase in the charged particle rate that is less than a specified fraction of the increase in the neutral rate. This is done in order to avoid triggering on charged-particle event encounters, such as those produced by spacecraft containing nuclear reactor power sources.

At the end of the mission, BATSE had detected:

- Total triggers: 8021
- **γ-ray bursts: 2704**
- Solar flares: 1190
- Magnetospheric events: 1717
- Terrestrial γ flashes: 76
  (see http://elf.gi.alaska.edu/sprites.html)
- Transient sources: 1999
- Soft γ-ray repeaters: 184
- Phosphoresence spikes: 35
- Unknown events: 33
- Accidental ot commended: 56
- Insufficient data: 27

Spatial distribution

- Why is this important?
  - Distribution can give indication of population of origin
  - Track the galactic distribution ?
- Measured by BATSE

Spatial distribution

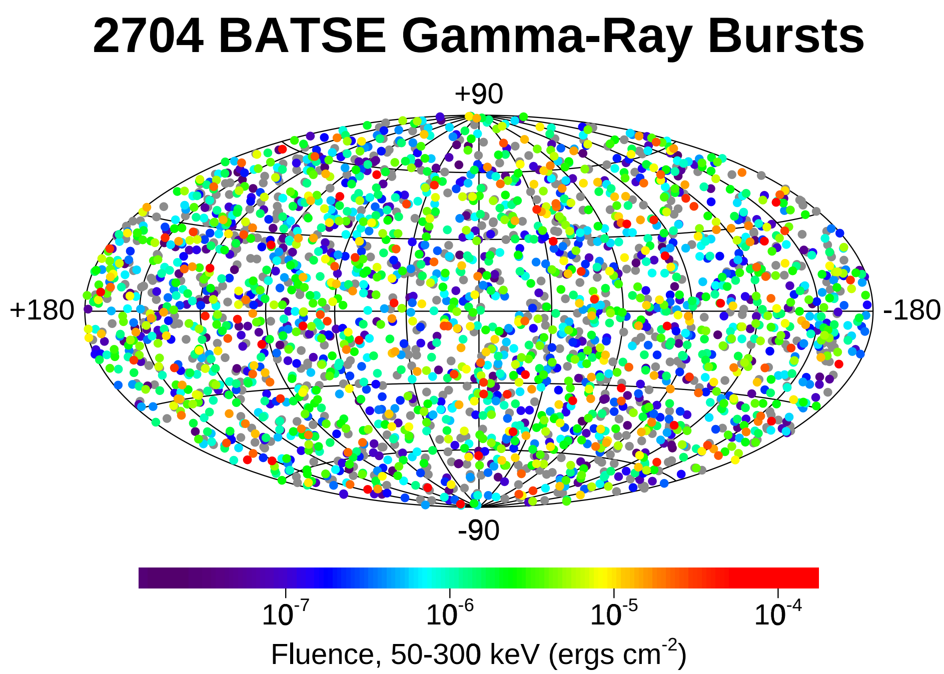


Figure 1: This map shows the locations of a total of 2704 γ-Ray Bursts recorded with the BATSE during the nine-year mission. The projection is in galactic coordinates;The burst locations are color-coded based on the energy flux of the burst integrated over the total duration of the event. Long duration, bright bursts appear in red, and short duration, weak bursts appear in purple. Grey is used for bursts with incomplete data.

Spatial distribution

- Different models for isotropic distribution
  - Oort Cloud
  - Galactic Disk– impossible with distribution of weak sources
  - Extended Galactic halo - Not seen for other Galaxies
  - Cosmological

Timing properties and distribution

- Why is this important?
  - timescale may give clues about size of region of origin
  - timescale may give clues on physics processes involved
  - If cosmological, should show time dilatation effects: fainter (farther) burst should be longer on average
- Measured duration varying from 0.001 to 1000 seconds!
- Double peaked distribution measured by BATSE
- Shorter bursts tend to have harder spectra

Timing properties and distribution

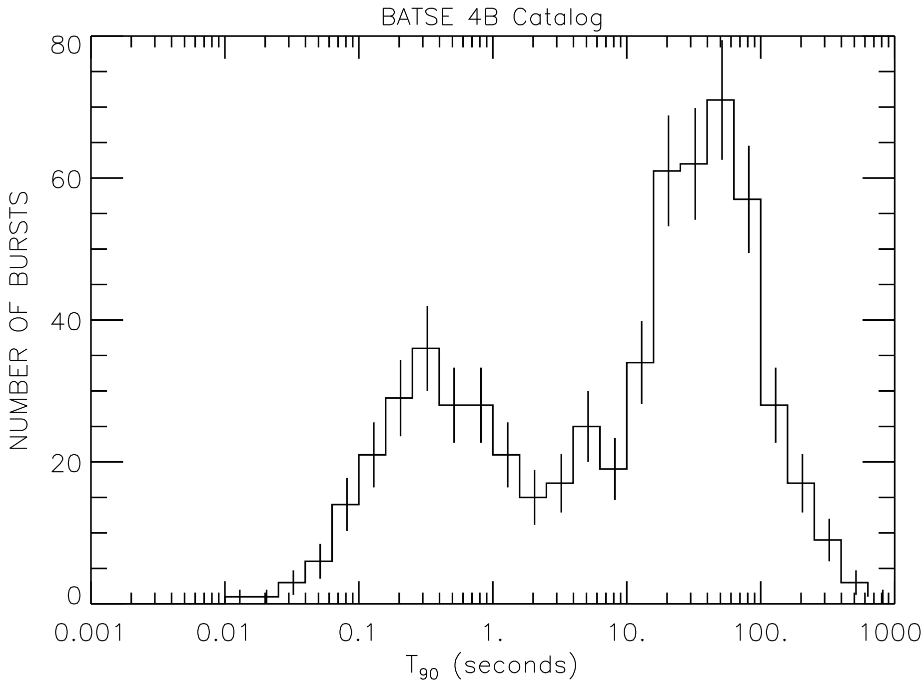


Figure 2: Time distribution of all BATSE bursts- The duration parameter used is T90, which is the time over which a burst emits from 5% of its total measured counts to 95%. Lightcurves used for the calculation of T90 are integrated over all 4 channels (E larger than 20 keV).

Light curves and spectral properties

- Bulk of energy above 0.1 Mev
- Non thermal spectra
- Distribution steeper at higher energy

Timing properties and distribution

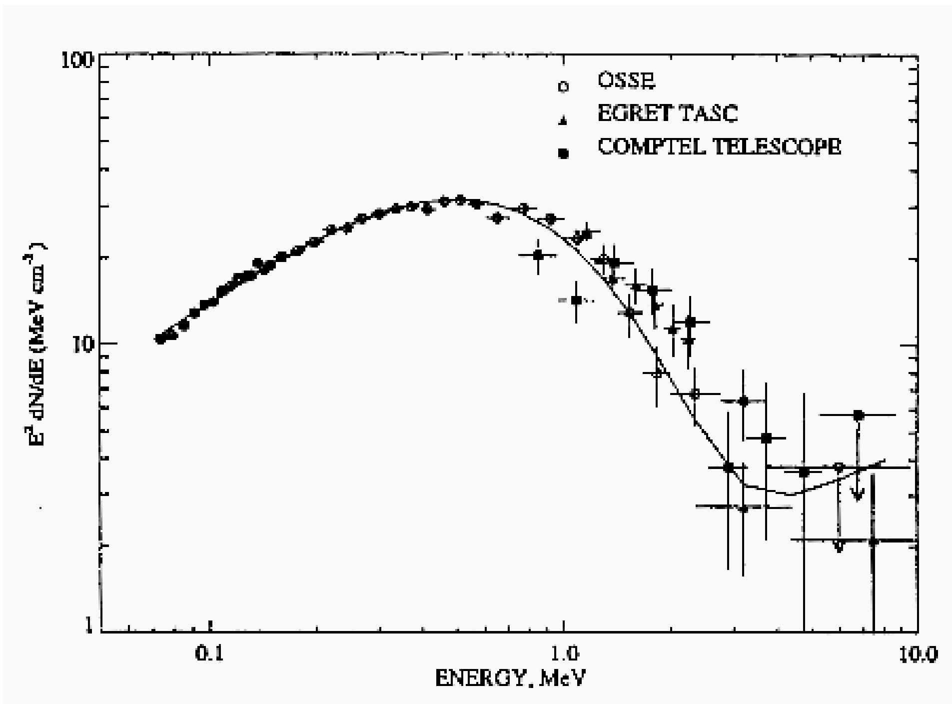


Figure 3: Spectrum of GRB 910601 observed over a wide range, as measured by three instruments on CGRO- It shows a typical broad spectrum with a peak at about 600 keV

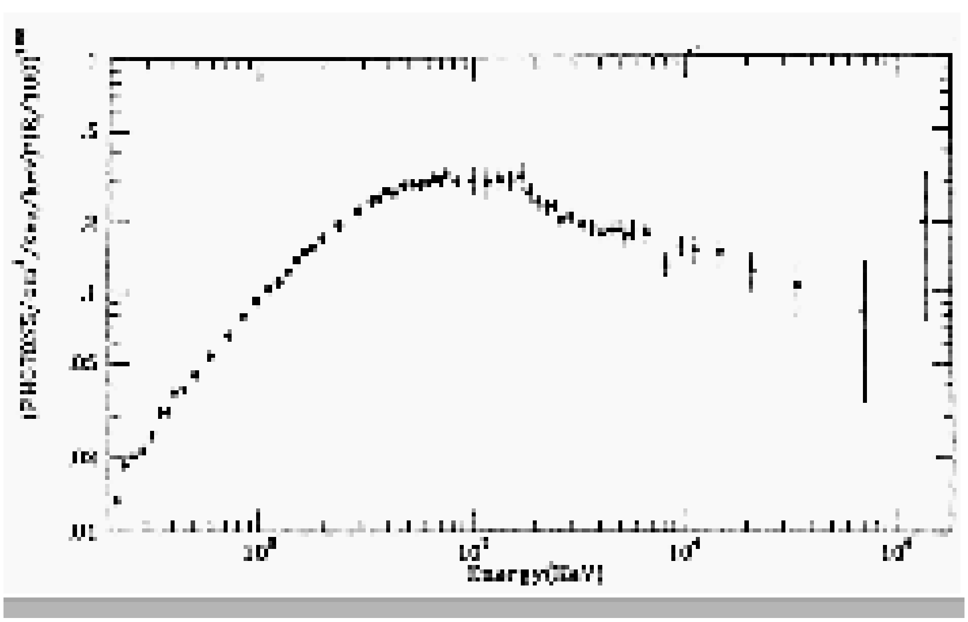


Figure 4: Same for GRB 910503 – with all four instruments on CGRO

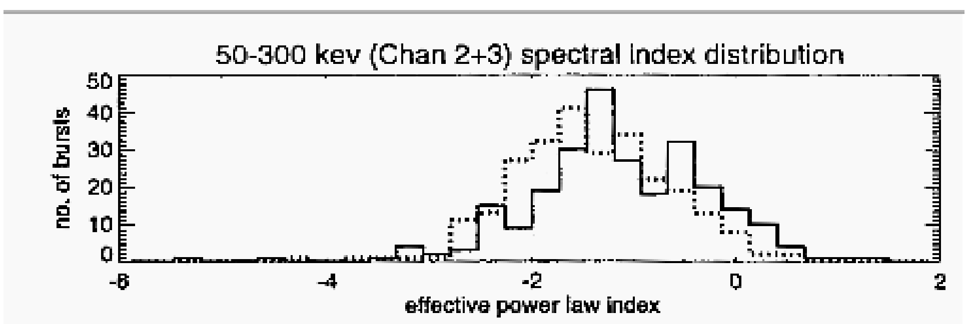
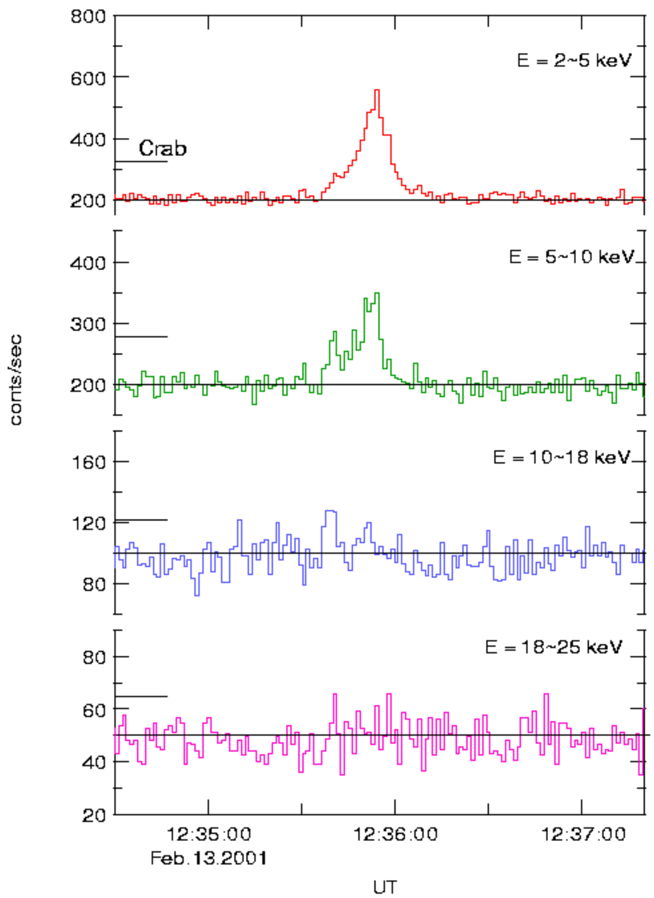


Figure 5: Distribution of power-law indices for a large number of bursts (measured by BATSE)

News and studies of counterparts

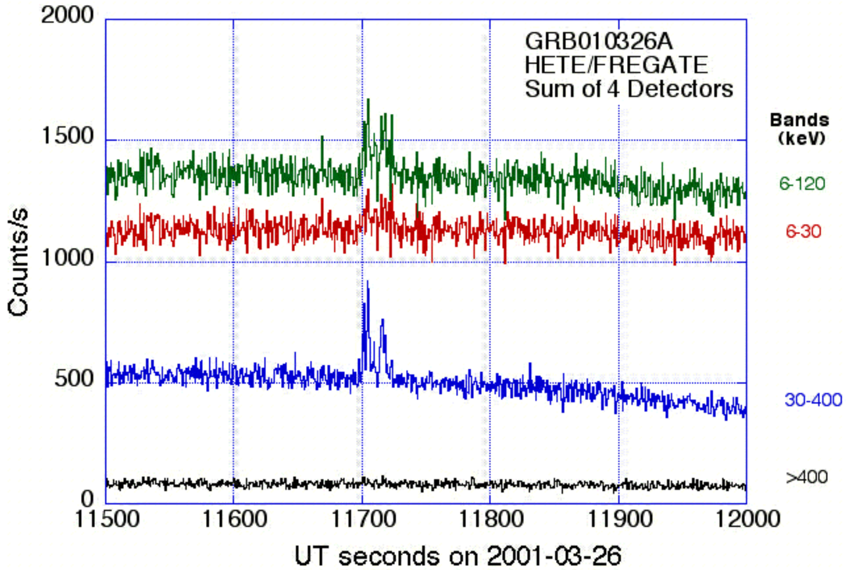
- Beppo-Sax (X-rays)
  - First identification of X-ray counterpart - GRB970228
  - 8 hours after the burst - fading fast
- Optical follow-ups – Found optical counterpart which went away after few days. (4.2 + HST)– Now 16 found
  - confirmation of host galaxy- Confirmation of cosmological distances
- Radio observations– GRB970508 using the VLA
- HETE2
  (check out: http://space.mit.edu/HETE/) New bursts!!

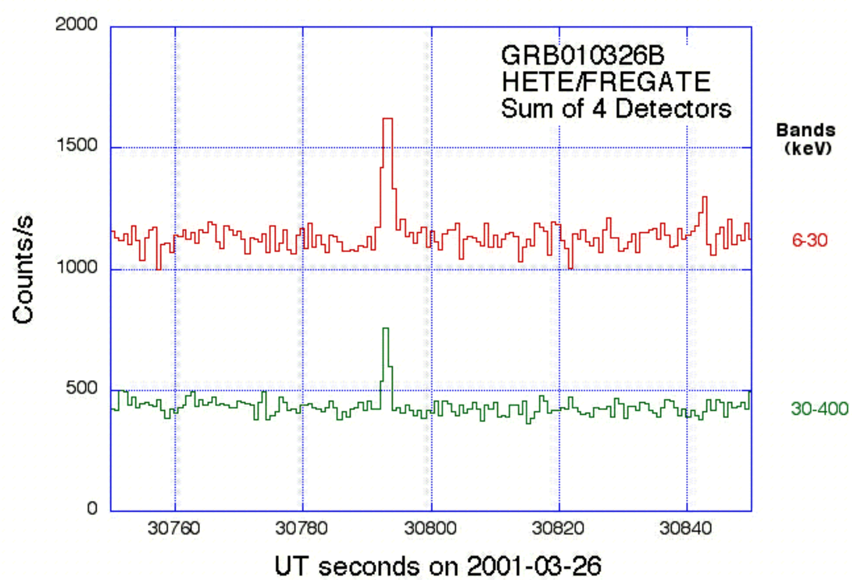
HETE-2



Light curve for the WXM instrument.

The Fregate light curve for GRB010326a




GRB010326B
HETE/FREGATE
Sum of 4 Detectors
Bands
(keV)
6-30
30-400
Counts/s
2000
1500
1000
500
0
30760
30780
30800
30820
30840
UT seconds on 2001-03-26

Some prevalent views- Recapitulation

Prevalent models involve fireballs and the collision of two neutron stars– Right energy (about 10^{53} ergs in neutrino)– The stars spiral toward each others (because they're losing energy by radiating gavitational waves) and then collide. One can estimate that there are 1 event like this every 10,000 to 1,000,000 year in a galaxy. BATSE observes a volume of space containing about 10 billion galaxies. So one would expect about 1,000 bursts per year- This is in agreement with observations.
The problem with this merger simple scenario is in the details–

- Converting neutrinos/antineutrinos in γ-ray
- Very inefficient process
- Almost thermal spectra
- Timescale not much longer than milliseconds
- Many heavy particles (protons, pions) in the fireball

Solution to this problem: shock wave acceleration of electrons which then emit γ-rays.

- Solve the thermal spectra problem (shock wave acceleration)
- Complicated light curves due to internal shocks

This model does predict afterglows in X-rays, UV, optical, IR and then radio.

Progenitors

Massive compact progenitors binaries (BH-NS or NS-NS system) forming a few solar mass black hole. Other explanations include formation of a magnetar (very high magnetic field neutron star, or tidal disruption of compact stars by million Solar mass black holes. So far, X-ray and optical afterglows are offset from the center of the host galaxy which contradict existing models of NS-NS merger- Large uncertainties and poor statistics so far-

Models Prediction

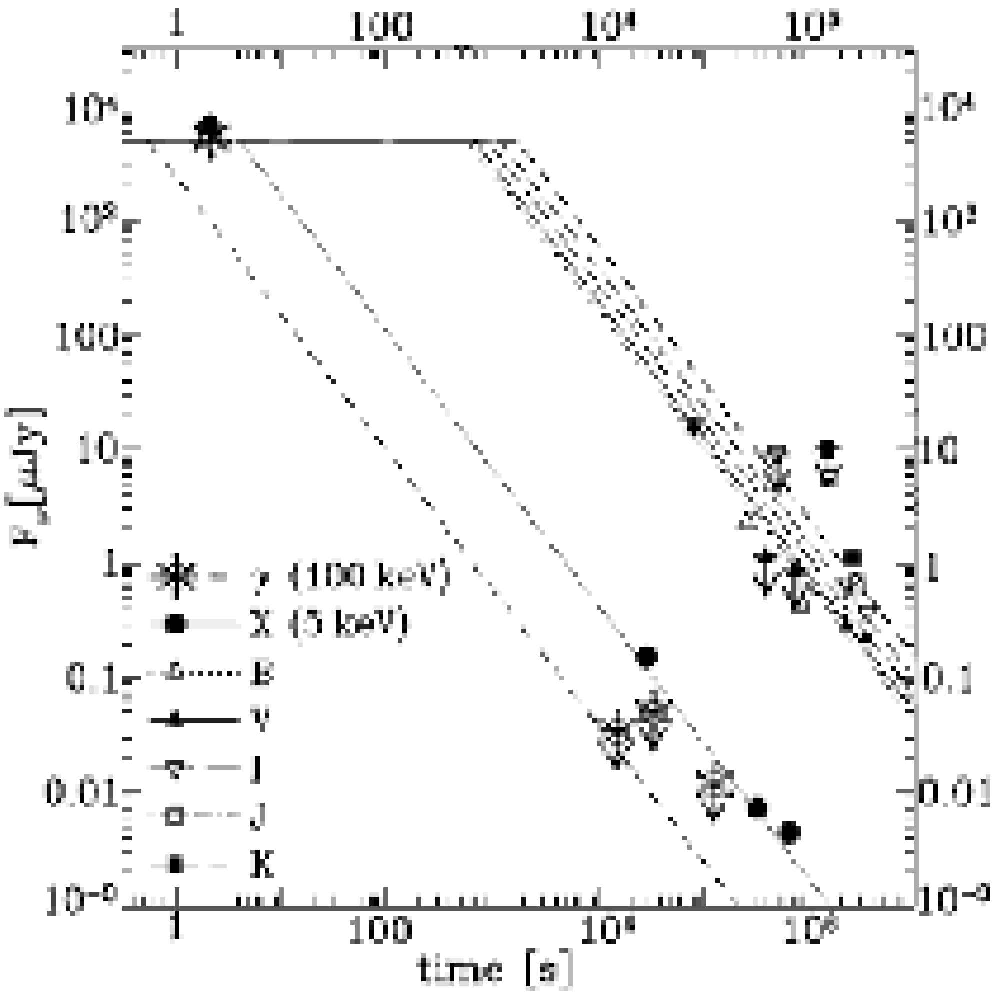


Figure 6: Comparison of the observed light curves of the afterglow of GRB 970228 at various wavelengths with the simple wave model predictions

More data expected from HETE-2 and Swift.